(c) Comparative Heat Release Rates for Aircraft Materials Measured in Different Apparatuses

by

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It may seem surprising that there have not been a significant number of studies reported in the literature where results from 3 or more HRR apparatuses are directly compared against each other. The best-known such study was one by Östman and co-workers [12]in 1985. In that study three apparatuses were examined against a wide range of test materials. The application of these findings was somewhat limited, however, since two of the three methods studied (the STFI apparatus and the OSU apparatus modified for oxygen consumption sensing) were not standard equipment or procedures. Only the third apparatus, the Cone Calorimeter, was a common apparatus used in its standard form. More specifically, all three methods examined by Östman used oxygen consumption as the measurement principle. Thus, differences seen between the apparatuses were due to such secondary effects as specimen size, sample holder arrangements, ignition mechanisms, and errors in calibration. The opportunity was still to come to subject a range to materials to apparatuses which differed in their very measurement principles, in addition to being of mechanically varied designs.

Such a opportunity arose in the aircraft area. The Federal Aviation Administration commissioned HRR tests to be run on a series of aircraft cabin wall-type panels. The panels were especially made up for this study and represented materials and construction methods found in the aircraft industry. The FAA also arranged to conduct full-scale tests [13]of the same materials to assess the actual expected behavior and to produce rankings; however the latter did not contain enough distinct performance differences to allow relative predictive merit to be assigned to the different bench-scale apparatuses. Thus, in this section we will examine only the results of the bench-scale comparisons. The five materials tested are described in Table 4. The materials were all honeycomb type of sandwich panels, but with differing materials used for the construction of the facings.

Table 4
Properties of the Test Specimens

Designation	Description
EP/FG	Epoxy glass facings, face and back 1-ply 7781 fiberglass impregnated with resin, fire retardant, and co-cured 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.36 lbs/sq ft
PH/FG	Phenolic glass facings, face and back 1-ply 7781 style woven fiberglass impregnated with a modified phenolic resin, and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.42 lbs/sq ft
EP/KE	Epoxy Kevlar™ facings, face and back 1-ply 285 style woven Kevlar impregnated with epoxy resin, fire retardant, and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.38 lbs/sq ft
PH/KE	Phenolic Kevlar facings, face and back 1-ply 285 style woven Kevlar impregnated with a modified phenolic resin and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.38 lbs/sq ft
PH/GR	Phenolic graphite facings, 1-ply 8 harness satin, 3K fiber T-300 woven graphite impregnated with a modified phenolic resin, and co-cured to 1/8 cell, 1.8 lb, 1/4-inch thick Nomex™ honeycomb. Outer surface covered with 2-mil white Tedlar™ Wt. = 0.36 lbs/sq ft

The test apparatuses used were the following:

- OSU/Thermopile
  These tests were conducted by the FAA. The arrangement used at that time was basically the standard configuration of the OSU method, as described in the ASTM E 906. The data examined included both an initial series of tests where the ASTM procedure was modified only by incorporating an improved baseline correction routine [14]and a second series, wherein the FAA revised both the test procedures and some of the test hardware [13]. The data do *not* include the current procedure, as described earlier in this Chapter, whereby the compensating tab is removed, the 3-thermocouple thermopile is replaced with a 5-thermocouple one, etc.

- OSU/Oxygen Consumption
  These tests were also conducted by the FAA. This was an adaptation of the OSU apparatus for oxygen consumption, similar to other such efforts described in Chapter 2.

- Cone Calorimeter
  These tests were conducted by NIST using standard Cone Calorimeter

test procedures; testing was done in both horizontal and vertical specimen orientations.

- Flame Height Apparatus
  This is a very different measuring principle from all the other ones considered. It entails a relationship observed between flame height and heat release rate. A few more details and the appropriate reference are given at the end of Chapter 2. These tests were conducted by NIST.

- FMRC Flammability Apparatus
  These tests were conducted by FMRC using their then-current procedures where the heat release rate is measured from specimens of well-defined exposed burning area.

Table 5 gives other details of specimen preparation and testing conditions.

The results which were obtained from each of the test apparatuses are summarized in Figures 2–6. Peak values are tabulated, since prior to finding that full-scale data did not permit a useful comparison, it was desired to compare the bench-scale data against a predictive method which is based on peak HRR data [15]. The aircraft panels tested were difficult-to-ignite, highly fire-retardant materials; as is typical with such materials, a fair amount of data scatter is noted in the results. With three test apparatuses, the Cone Calorimeter, the FMRC Flammability Apparatus, and the Flame Height apparatus the results were generally close, ranging from about ±5% for the case of the specimens in Figure 6 to about ±25% in the worst case (Figure 2). In general, for these three methods the results can be considered in reasonable agreement, to within the general scatter of the data. (The average coefficient of variation, i.e., the standard

Table 5
Specimen Testing Conditions

Test method	Orientation	Specimen size (mm)	Test heat fluxes (kW/m^2)	Surface condition
OSU/Thermopile[a]	V	150 × 150	25, 50, 75	as received
OSU/Thermopile[b]	V	150 × 150	35	as received
OSU/O_2	V	150 × 150	25, 50, 75	as received
Cone Calorimeter	H	100 × 100	25, 50, 75	as received
Cone Calorimeter	V	100 × 100	25, 50, 75	as received
Flame height	V	284 × 284	20, 25, 30, 37	as received
FMRC	H	100 × 100	26, 39, 61	blackened

[a] Using initial testing procedure.
[b] Using revised testing procedure.

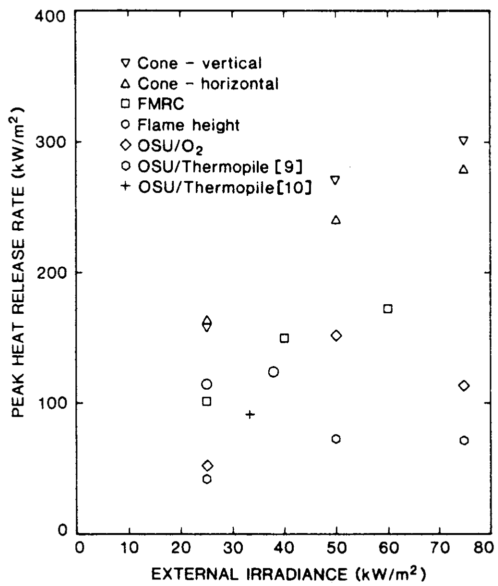

Figure 2. Rate of heat release for specimen EP/FG (a = tested by initial FAA procedure; b = tested by revised FAA procedure).

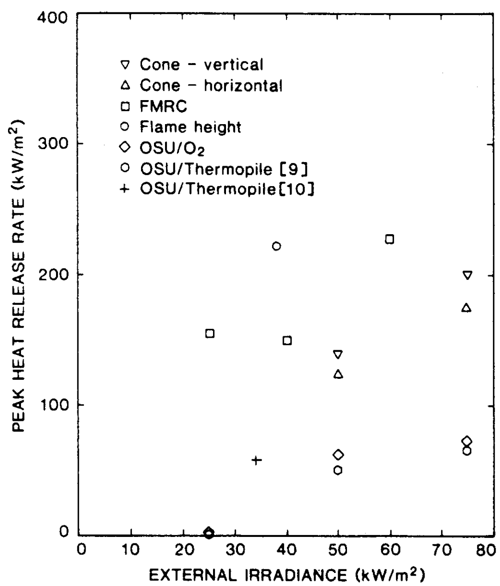

Figure 3. Rate of heat release for specimen PH/FG.

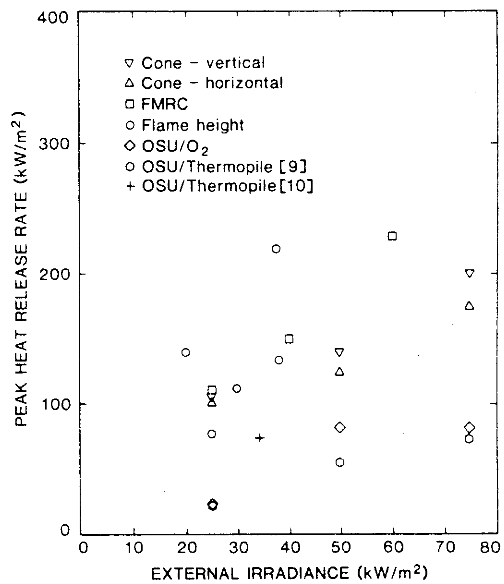

Figure 4. Rate of heat release for specimen EP/KV.

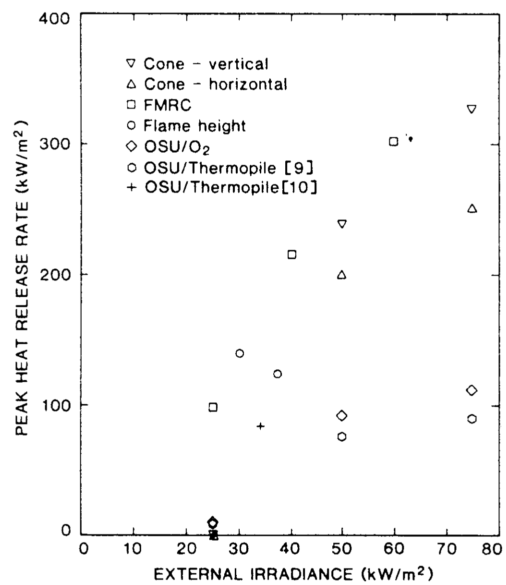

Figure 5. Rate of heat release for specimen PH/KV.

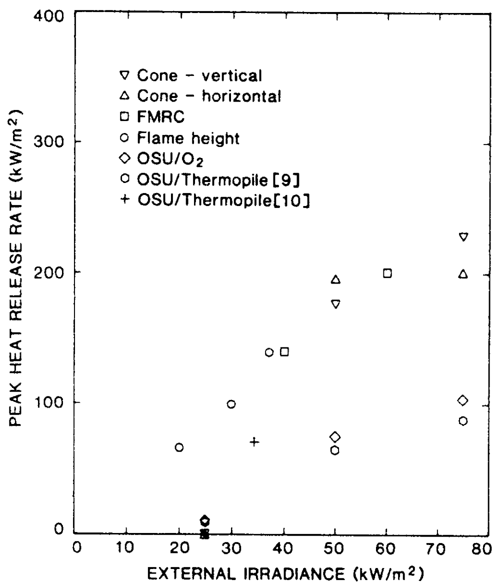

Figure 6. Rate of heat release for specimen PH/GR.

deviation expressed as a fraction of the mean, was 8.4% for the Cone Calorimeter; it is estimated that the coefficients of variation for the other apparatuses were also in the range of 5% to 10%.)

Since the Cone Calorimeter tests were conducted in both orientations, the data can also be examined from the point of view of *orientation effect.* A slight, but systematic effect can be seen whereby higher heat release rate values hold for the vertical orientation than for the horizontal. Such a relationship is not always obtained; data for red oak, for instance, show the opposite trend [16]. Thus, the aircraft panels' increased heat release rate in the vertical orientation may be due to some specific thermostructural features of the panels, possibly related to the way the outer layers tend to delaminate and curl during the test exposure.

The values from the OSU apparatus, as tested with the original FAA procedure were consistently about half the value of data from the other instruments. The differences between OSU/thermopile and OSU/O_2, however, were not so pronounced, being typically 10 to 20% higher for the O_2 mode. Starting with the second series of FAA data reported for the OSU/thermopile method and continuing for several more years, the FAA has been conducting roundrobins, inspecting test laboratories, and otherwise attempting to reduce systematic calibration errors in the OSU apparatus, and to modify procedures in such a way as to lead to both greater repeatability and reproducibility. Their current approach

has been delineated earlier in this Chapter. Thus, part of the outlier nature of the OSU data may be attributed to imperfect laboratory procedures. On the other hand, at the time these tests were being conducted no roundrobin or calibration improvement efforts had been undertaken for any of the other methods examined; thus, the comparison was, in that sense, unbiased.

In conclusion, we find it very encouraging that the data from the Cone Calorimeter and the Flame Height Apparatus, which operate on such totally different measuring principles, would agree so closely. Similarly, while the Cone Calorimeter and the FMRC Flammability Apparatus both use oxygen consumption, there is not much in common with the mechanical design or the operating procedures of these two apparatuses. Thus, agreement here is, again, impressive. The failure of the OSU/O_2 data to agree with the other oxygen consumption-based methods points towards a different lesson. The test data from a measuring apparatus will never be better than are the calibration procedures of the equipment. How successful these may is, indeed, the sort of question which can be partially answered by a comparison program of the type described here.

While interesting, the results of the study given here do have some serious limitations. The materials tested, while showing a range of fire behaviors, nonetheless shared similar thicknesses, thermal properties, and burning times. We may speculate that the reason more ambitious comparison programs have not been conducted is that the need was not there. The selection of a proper or optimal measuring apparatus in affected by many considerations. A comparison, such as this one, can give only partial guidance on only one factor: *validity.* Absolute measures of validity for a bench-scale HRR method for testing solid materials cannot be established. In programs such as this one, however, when a sufficiently large number of test methods and test materials can be assembled, at least inferences of validity may be made. Namely, the preponderance of apparatuses of fundamentally different design can yield similar values, but one method is found to be an outlier, it may be surmised that the error lies with the outlier and not with the remainder. Such assessment requires that the results do show agreement among most of the apparatuses. If the results had, instead, shown wide scatter among all of the apparatuses, few conclusions could be drawn.

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